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Thick Film Layout Considerations

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ABSTRACT

This technical note describes the preliminary layout considerations for thick film materials. The available and improved materials are discussed and their related electrical characteristics are listed. Resolution and power dissipation relationships are also presented.

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THICK FILM LAYOUT CONSIDERATIONS

The Integrated Circuit Facility in Group 73 uses thin film and thick film techniques and monolithic semiconductor chips in the fabrication of hybrid integrated circuits.

Although some primary and supporting areas of the facility are not yet completed, a number of circuit and system problems have been successfully undertaken for various groups in the Laboratory.

In order to aid circuit and system designers in understanding the integrated circuit process advantages as well as the limitations, periodic technical memorandums will be distributed on various phases of integrated circuit fabrication techniques.

Initially, the technical memorandums will provide a limited description of the materials and processing procedures and will concentrate on the techniques for converting typical circuit problems to an integrated circuit implementation. For example, the relationships of substrate area, power dissipation, thermal coefficients, and other electrical characteristics primarily of interest to the circuit designer will be the subject of the early memorandums. This technical note will consider these electrical characteristics as they relate to the thick film process.

Since thick film technology continues to progress in the reduction of line widths and spacing as well as multilayer techniques, the discussion here must be considered as representing a transitory point in thick film techniques.

Thick film materials are available from several manufacturers in the form of pastes that consist of mixtures of organics, low melting glass and primarily silver and palladium metals. The proportion of glass and metal allows a resistivity range from a few ohms per square to one megohm per square.

By screen printing methods the pastes are applied to ceramic substrates to form appropriate circuit resistors and then fired to obtain stable elements.

The firing profile (time at peak temperature and heating rate) determines the final resistance, temperature coefficient, noise characteristic and other related characteristics of the resistor.

Generally, the two major considerations in designing the thick film circuit are minimum size and fabrication simplicity. Minimum size is an obvious goal in any design, while fabrication simplicity relates directly to low cost and reliability.

Thick film resistor values may be defined in the usual manner,

$$R = \frac{\rho \ell}{A} \tag{1}$$

where ρ is the resistivity in ohm-centimeters, ℓ is the resistor length and A is the resistor cross-sectional area. Equation (1) may be rewritten as

$$R = \frac{\rho \ell}{wT}$$

where T is the resistor thickness and w is the resistor width.

Let the ratio $\frac{\ell}{w} = n$

where n is defined as the number of squares, then

$$R = \frac{\rho n}{T} \quad .$$

A simple convention, particularly useful for layout purposes, employs a sheet resistivity ($\Re$) defined in ohms per square ($\Omega/\square$).

Let $\frac{\rho}{T} = \Re$

where $\Re$ is the sheet resistivity per unit area or per square at a constant thickness (usually 1 mil for most thick film resistors), then

$$R = \Re n \quad . \tag{2}$$

If, for example, a thick film material having a sheet resistivity ($\Re$) of 10 k$\Omega/\square$ is employed and the resistor length-to-width ratio is 4, then the total resistance is

$$R = \Re n$$

$$R = 10 \frac{k\Omega}{\square} \times 4\square$$

$$R = 40\ k\Omega$$

By this artifice, the layout of resistor values may be based only on a proper relationship of the length-to-width ratio and the sheet resistivity value.

The case of a resistor design in which the aspect ratio is less than unity ($\ell < w$) can be handled in the same manner. For example, a material having a sheet resistivity ($\Re$) of 10 k$\Omega/\square$ and an aspect ratio of 0.25 has a total resistance of 2.5 kΩ. Figure 1 indicates these two examples of resistor design.

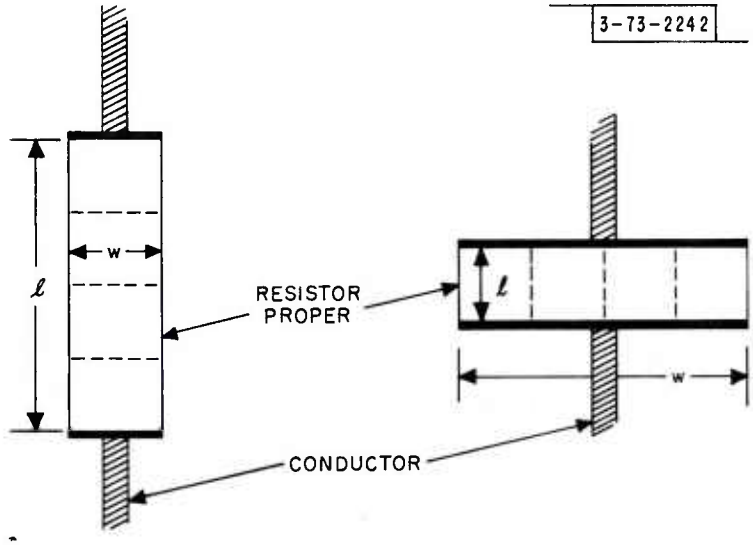

Fig. 1. Two thick film resistor configurations.

$$\Re = 10 \frac{k\Omega}{\square}$$

$$\frac{\ell}{w} = n = 4 \text{ squares}$$

$$R = \Re n = 40\ k\Omega$$

$$\Re = 10 \frac{k\Omega}{\square}$$

$$\frac{\ell}{w} = n = \frac{1}{4} \text{ squares}$$

$$R = \Re n = 2.5\ k\Omega$$

Since each resistor design attempts to achieve minimum area, it may be assumed that either the resistor length or width is chosen as a minimum value consistent with processing resolution. Power considerations may dictate more than this minimum area and this will be discussed later, but for the moment we might define a minimum square where the length and width are equal and as small as the process will tolerate. The minimum square concept is particularly convenient in calculating the total area required for the circuit resistors, but it leads to some confusion when the resistor aspect ratio is less than unity. In Fig. 1, for example, each resistor has four equal squares from an area consideration, but using the earlier derivation resistor A has four squares while resistor B has 0.25 square. This contradiction is avoided if we amend the earlier derivation in the following manner.

$$R = \Re n_s$$

$$n_s = \frac{\ell}{w} \qquad (\ell > w) \tag{3}$$

$$R = \Re n_p$$

$$n_p = \frac{w}{\ell} \qquad (\ell < w) \tag{4}$$

This allows us to employ the minimum-square concept and relate to electrical representation by treating the resistor with an aspect ratio greater than unity as having minimum squares in series, and the aspect ratio less than unity as a parallel arrangement of minimum squares.

From Fig. 1 it should be clear that minimum resistor area occurs when the paste resistivity is matched to the particular resistor value.

At the present time not all pastes having different resistivity values can be cofired; hence, in any multiresistance circuit, minimum area is achieved by selecting a particular paste resistivity that best matches the various resistor values.

Table I illustrates a simple case of six resistors and the area required for two different paste sheet resistivities. If these were the only pastes available, minimum area would result for the 10-kΩ/□ paste.

TABLE I

EXAMPLE OF RESISTOR AREAS
FOR DIFFERENT SHEET RESISTIVITY VALUES

Circuit Resistor Values		Paste Resistivity	
		1 kΩ/□	10 kΩ/□
		No. of Minimum Squares	
1 each	1 kΩ	1	10
4 each	10 kΩ	40	4
1 each	50 kΩ	50	5
		91	19

Since it is unlikely that pastes of greatly different sheet resistivities can be conveniently cofired and in order to reduce the art work and number of screen printing operations, an exercise or calculation as shown in Table I will be necessary for each circuit layout. At present, a computer program, Resist 1, is available for providing the layout man with the optimum paste resistivity (from a listing of available pastes) for a circuit with many resistors of different values.

The resistor area, of course, is also influenced by the power dissipation required of the resistor. Thick film material on a ceramic substrate will dissipate about 20 watts per square inch.* On a somewhat more practical scale, this is equivalent to 20 microwatts per square mil.

Prior to the layout of any circuit, the Circus program is used to analyze the circuit in detail, including the maximum power level of each resistor. This information is used in modifying the Resist 1 results in the event that greater resistor area is required for power reasons.

* This power rating is based on a 10°C rise and unless there is a large percentage of substrate occupied by the resistor, fringing effects provide a large safety factor.

At the present time, we can achieve a minimum resistor width of 20 mils (10 mils will be practical shortly) and hence the power rating for a minimum square is about 8 mw.

The ultimate capability of thick film resistor line widths is probably about 3 mils, while conductor and pad minimum line width hopefully can be reduced to about 1 mil.

As better resolution is obtained, however, additional concern for power dissipation must be exercised. At some point, depending on the resistor value, the power dissipation consideration may play a more predominant role in establishing the minimum resistor area than the resolution.

By using the Circus program to determine exact power dissipation level for each circuit resistor and using this information as additional inputs to the Resist 1 program, the minimum resistor area and the proper resistivity can be determined easily.

However, by generalizing so that each circuit resistor is assumed to dissipate a power of V^2/R, where V is the maximum circuit voltage, a relationship between minimum area and resistor value as shown in Fig. 2 is obtained for a 6-volt system.

The effect of different resolution is shown on Fig. 3. Again, for a 6-volt system, this figure shows that, as better resolution is achieved, the minimum resistor value for which a single square can be used increases because of power requirements. It must be remembered that as the resolution decreases, the dimensions of the minimum square also decrease.

At a resolution of 20 mils, Fig. 3 indicates that only for resistor values less than 3.5 kΩ will an area greater than one square be required to satisfy the power dissipation.

As the resolution reaches 5 mils, all resistor values less than 72 kΩ may require greater than one square. Since these figures are based on a particular supply voltage and assume maximum power dissipation, they are intended only as a guide and indicator of the relationship of resolution, power dissipation and area for resistor design.

The present resistor tolerance range after firing is approximately 10 to 20 percent and final adjustment to within 5 percent is achieved by air abrasion techniques.

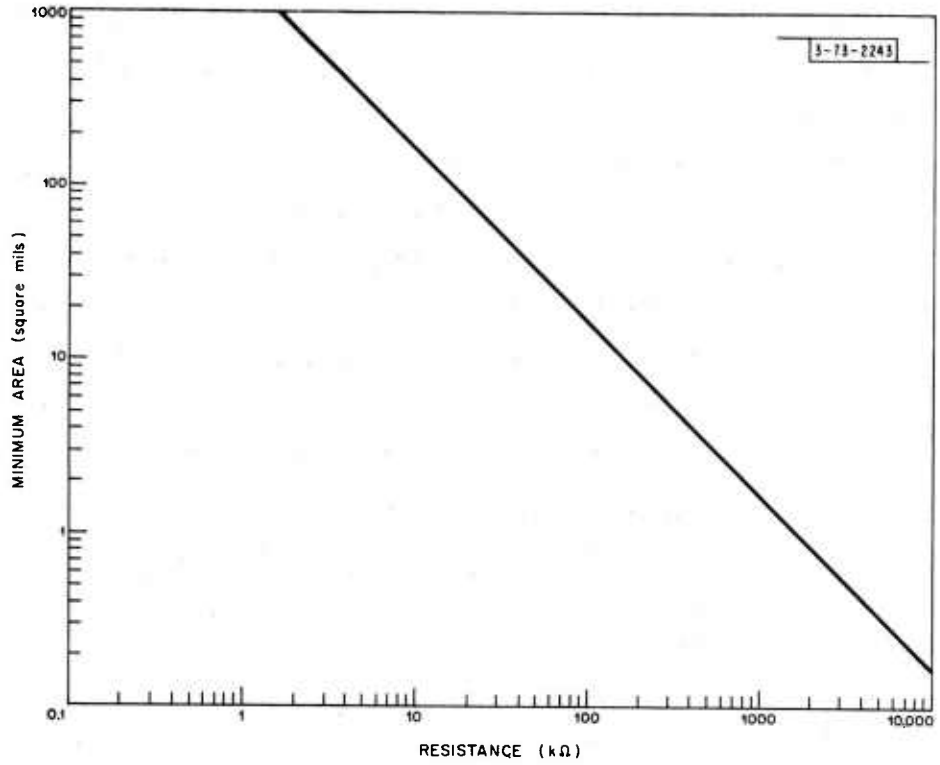

Fig. 2. Minimum resistor area required for adequate power dissipation in 6-volt system.

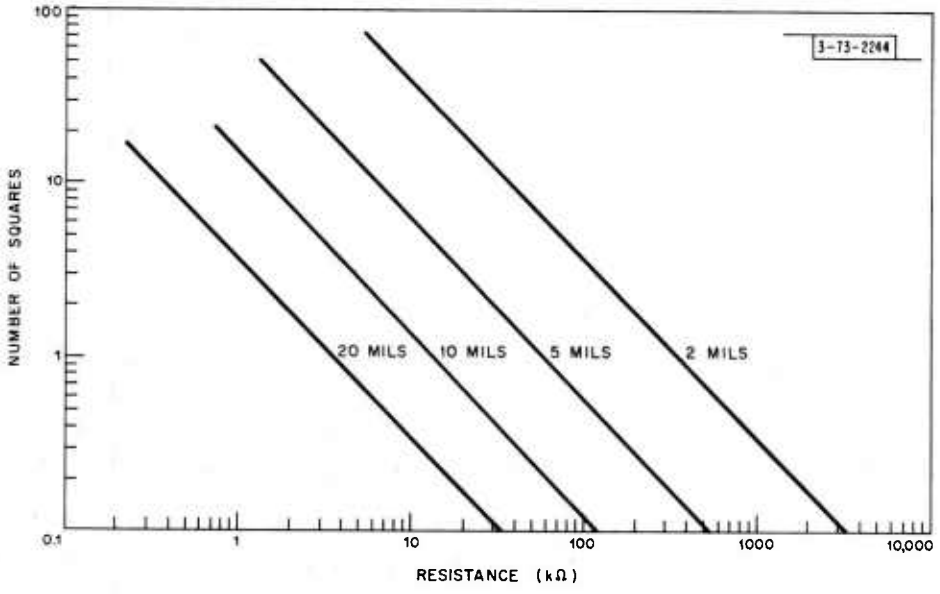

Fig. 3. Minimum number of squares for power dissipation at various resistor width resolutions.

Electrical trimming of resistors appears feasible, particularly for low values, and there are other promising methods under development that may replace abrasive trimming.

Some conditioning of resistors by voltage or current pulsing may be desirable to obtain long-term stabilization, particularly against accidental overvoltage conditions that may occur during later use of the circuits.

A glaze material is used as a final overcoating for the thick film resistors that protect the elements against moisture and contamination.

The temperature coefficients and other characteristics of the present thick film materials as well as newer materials under evaluation are listed below.

Material Type	Resistivity Range	Temperature Coefficient	Noise Level
Resistor paste ES-6900 series	10 ohm/sq.– 100 kΩ/sq.	180 ppm/°C avg.	–5 to +18 db
Resistor paste ES-700 O series	100 ohm/sq.– 1 MΩ/sq.	150 ppm/°C to 350 ppm/°C	–2 to +15 db
Conductor paste (Pt-Au) ES-5800 B DuPont 7553	0.08 ohm/sq.		
Conductor paste (Au) ES-8800 B	0.008 ohm/sq.		
Conductor paste (Ag) ES-590 ES-5964 DuPont 7713 DuPont 6233	0.007 ohm/sq.		

Present layout experience indicates that the substrate area allocated to resistors varies from 10 to 30 percent depending on the circuit type, and conductor and pad area vary from 20 to 30 percent. The unused substrate area is relatively constant at about 50 percent for the present 20-mil resolution.

Some area trade-off between thick film conductors and wire-bond jumpers is possible, but overall reliability is increased if the number of wire bonds is minimized. Present bonding procedures will be the subject of a later technical

note, but it might be noted here that active elements are ultrasonically bonded to appropriate thick film pads and thermocompression wire bonds from the devices to pads and from substrate pads to the package leads are employed.

Thick film capacitors are under development to minimize the need for chip type capacitors separately attached to the substrate. The capacitor and multilayer fabrication techniques will be described in a separate technical note.

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13. ABSTRACT

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14. KEY WORDS

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